ANSYS CFD results for the AIAA High Lift Prediction Workshop

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Outline

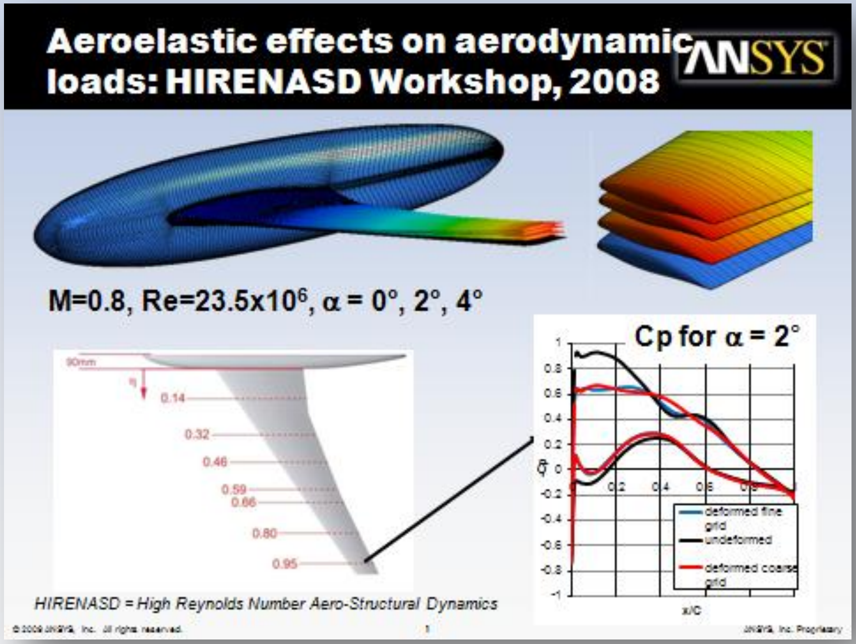
Method	3 minutes	Discretization	Solution Strategy	Turbulence Modeling
Workshop Results	9 minutes	Grid selection	Results update	Interesting observations
Lessons learned	3 minutes			
Feedback	5 minutes			

About ANSYS

- **Worldwide presence**
  - 1,600 employees
  - 60+ locations & network of 200+ channel partners in 40+ countries
  - 21 major development centers on 3 continents
  - ~500 developers worldwide
- **Develop and market a broad range of advanced simulation tools**
  - Structural Mechanics
  - Fluid Dynamics
  - Electromagnetics
- **Many CFD solutions**
  - General purpose
    - ANSYS FLUENT
    - ANSYS CFX
    - ANSYS CFD (CFX + FLUENT)
  - Special purpose
    - Airpak, Icepak, POLYFLOW, BladeModeler, Turbogrid
  - Integrated
    - FLUENT for CATIA v5

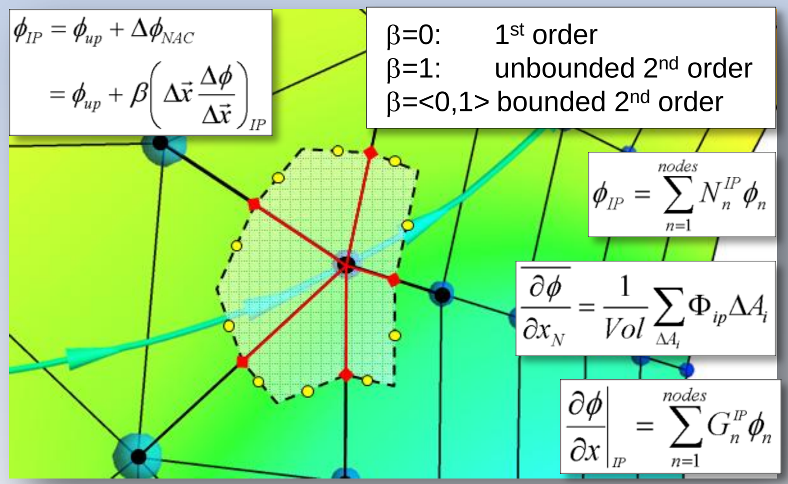
Solver

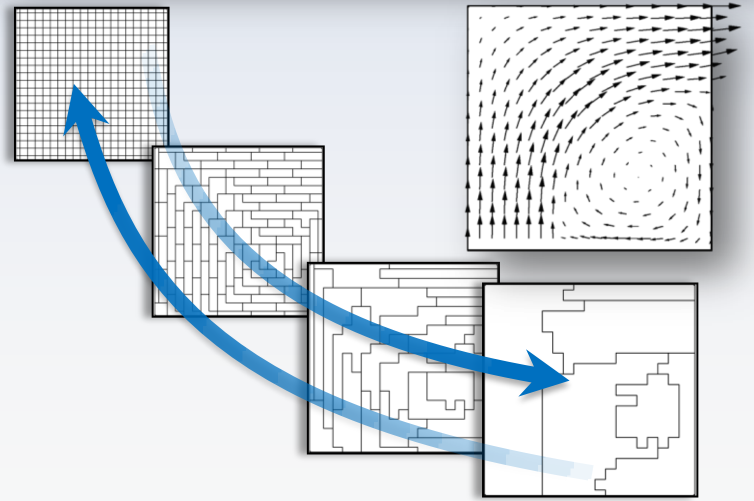
- **ANSYS CFX used for all analyses**
  - Chosen because of existing integration with ANSYS Mechanical for Fluid Structure Analysis (FSI)
  - No FSI used in workshop, but important to design
    - Consider for future work



Discretization and Solution Method

- **Discretization**
  - Element Vertex Finite Volume Method
  - 2nd order High Resolution (bounded) upwind advection
  - Rhie-Chow for pressure-velocity coupling.
- **Solution Method**
  - Implicitly coupled Mass and momentum
  - Linear equations solved using Coupled Algebraic Multigrid.
  - Timestep to control convergence





Mass: Co-located, All Speed

$$\dot{m}_{ip} = \rho_{ip} u_{j,ip} \Delta A_{j,ip}$$

- **Implicit all-speed Newton Raphson linearization:**

$$\left(\rho u\right)^n \approx \rho^n u^o + \rho^o u^n - \rho^o u^o$$

- **Density transport treatment, implicit in pressure via EOS:**

$$\rho_{ip} = \rho_P + \beta \left(\nabla \rho\right)_{ip} \cdot \Delta \vec{x}_{ip}$$

- **P-V coupling via momentum analogy achieves co-location:**

$$u_{ip} = \hat{u}_{ip} + d_{ip} \left(\frac{\Delta p}{\Delta x} \right)_{ip}$$

- **Importance:**
  - All speeds/equations of state supported
  - Natural low-to-high speed numerics
  - Implicit in pressure and velocity

Timestep selection

- **Timestep based on Mean Aerodynamic Chord (MAC)**

  `MAC Timescale = MAC/airspeed`

- **Could run as large as**

  `MAC Timescale x 10`

  Periodically stable after ~150 iterations

  – Same periodic behavior with MAC Timescale x 1.0

  Stable within ~200 to 300 iterations

- **Best behavior with**

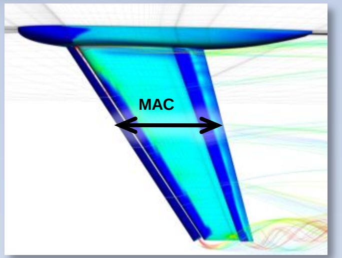
  `MAC Timescale/10` and 2 additional coefficient loops

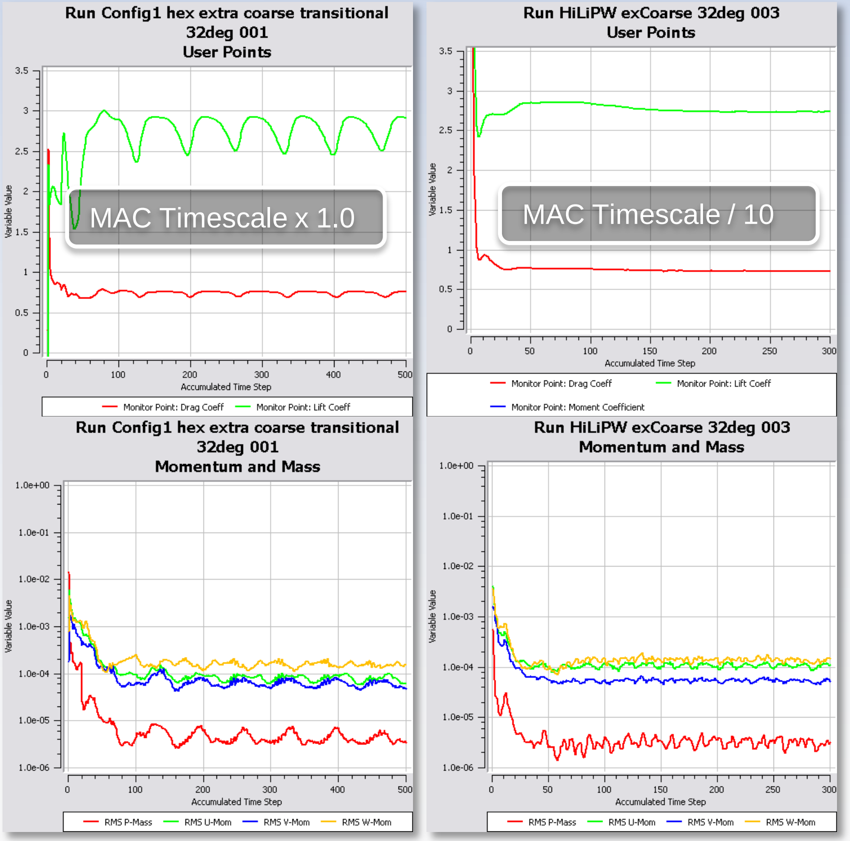
- **Smaller timestep required for medium grid due to face angles (0.9 degrees!)**

  `MAC Timescale/100`

  Stable within ~800 iterations

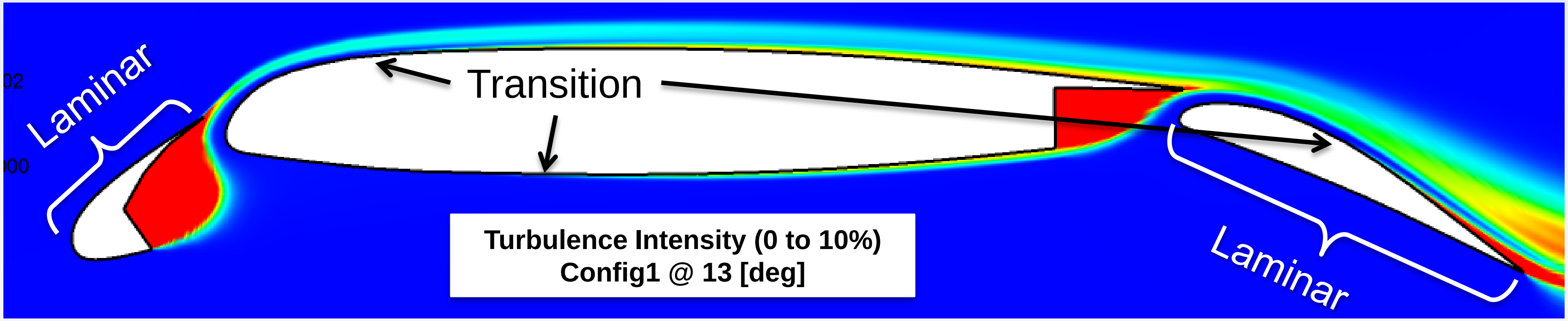
  – Increased overall number of iterations but additional coefficient loops not required





Turbulence Modeling

- **SST + Menter's Gamma-Theta predictive transition model**
  - Solves 2 Transport Equations
    - Intermittency (γ) Equation
    - Transition Onset Reynolds number Equation
- **Used Menter-Langtry Onset Correlation**
- **Multiple transition mechanisms**
  - Natural, Bypass, and Separation induced transition



Turbulence Intensity (0 to 10%)
Config1 @ 13 [deg]

Additional notes

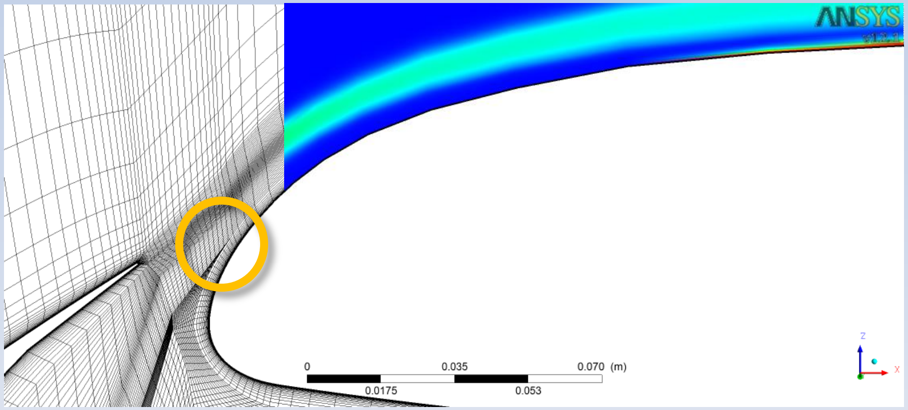
- **Non-standard solver settings**
  - High Resolution (2^{nd} order iteratively bounded) advection scheme for turbulence equations
    - Required for transition modeling but also applied to fully turbulent cases for consistency
  - Added extra coefficient loops (2 to 3) to steady the solution
    - Feedback due to sharp transition location
    - Steady state uses pseudo-transient scheme instead of under relaxation
      - Ran transient with 1^{st} order backward Euler scheme to allow additional coefficient loops
- **Comments on convergence**
  - Residuals were reduced but never fully converged
    - Possibly due to grid quality but may also relate to flow instability
  - Small fluctuations in integrated quantities (CL, CD, CM) still observable
  - Iteration (convergence) error was greater than discretization (grid convergence) error but small relative to experimental error

References

- **Solver**
  - Menter, F.R., Galpin P.F., Esch T., Kuntz, M, Berner, C., (2004), *"CFD Simulations of Aerodynamic Flows with a Pressure-Based Method"*, 24th International Congress of the Aeronautical Sciences, ICAS 2004.
- **Transition Model**
  - Menter, F.R., Langtry, R.B., Likki, S.R., Suzen, Y.B., Huang, P.G., and Völker, S., (2004), *"A Correlation based Transition Model using Local Variables Part 1- Model Formulation",* ASME-GT2004-53452, ASME TURBO EXPO 2004, Vienna, Austria.
  - Menter, F.R., Langtry, R.B., Likki, S.R., Suzen, Y.B., Huang, P.G., and Völker, S., (2004), *"A Correlation based Transition Model using Local Variables Part 2- Test Cases and Industrial Applications",* ASME-GT2004-53452, ASME TURBO EXPO 2004, Vienna, Austria.

Grid Used and Runs Completed

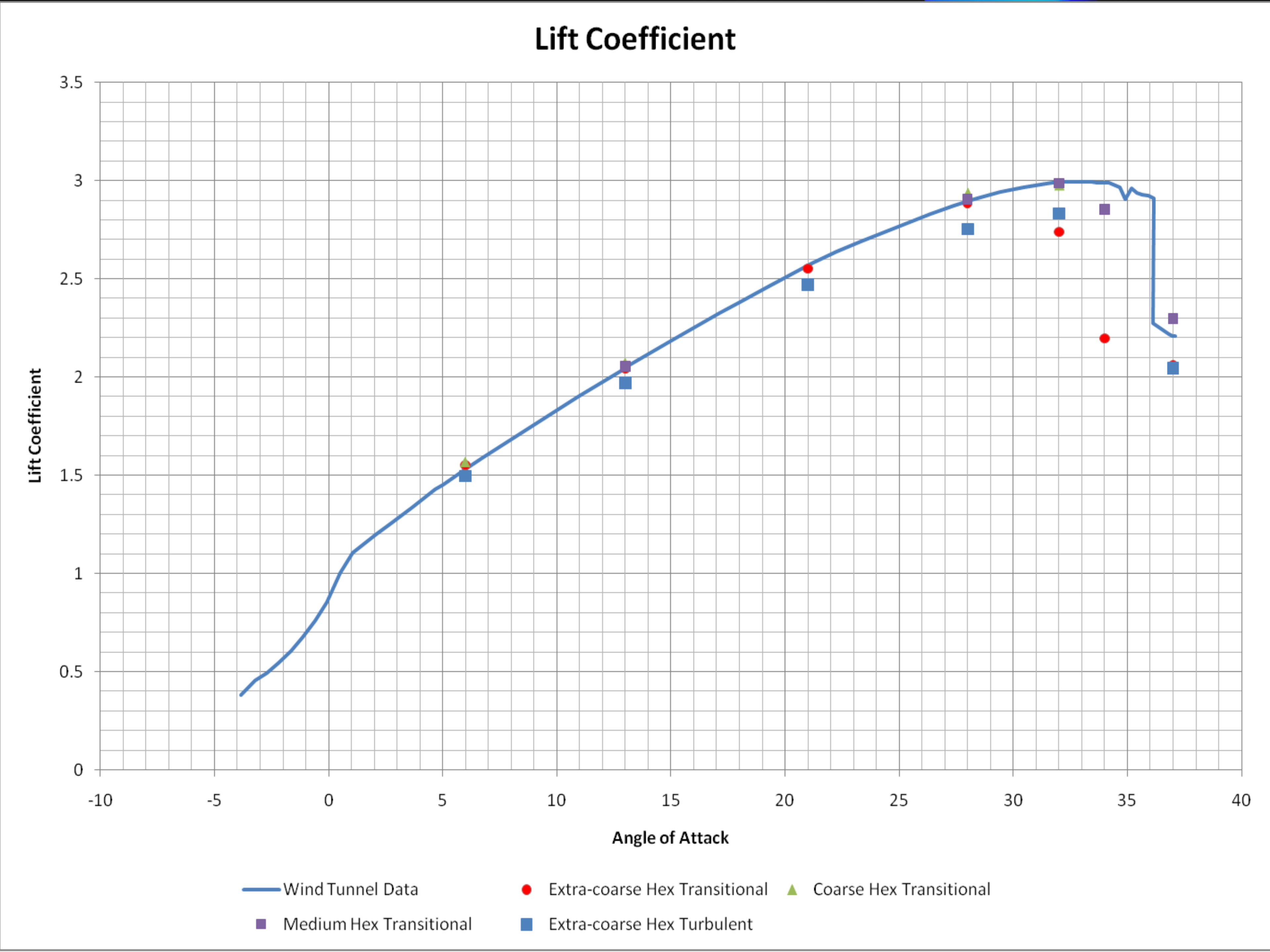
- **Grid**
  - Unst-Hex-FromOnetoOne-A-v1
- **Solver**
  - ANSYS CFX 12.1
- **Due to resource restrictions, not all points were run**

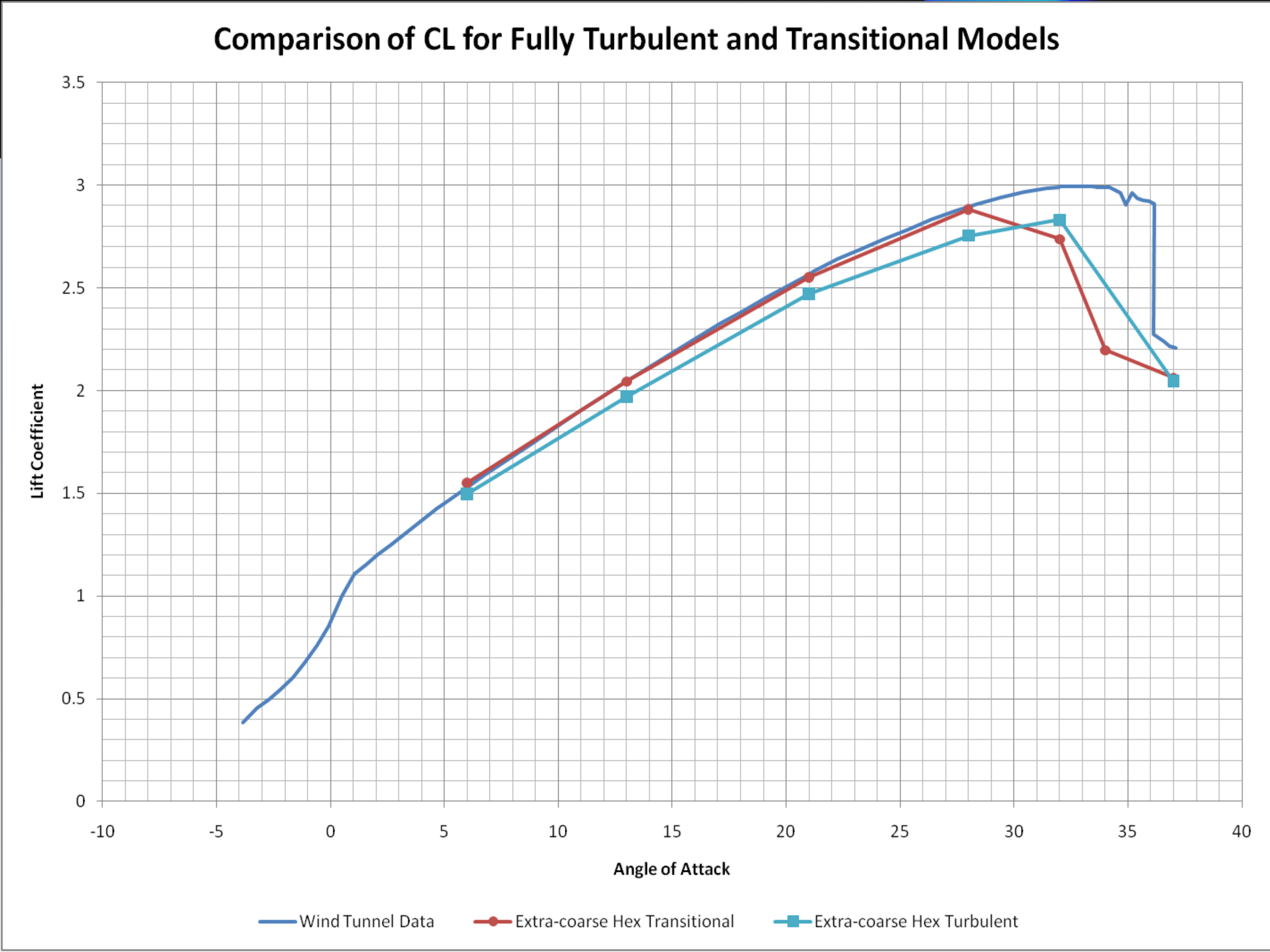


	Nodes	Elements
Extra-coarse	6,068,737	5,957,632
Coarse	20,356,741	20,107,008
Medium	48,104,801	47,661,056
Fine	161,853,985	160,856,064

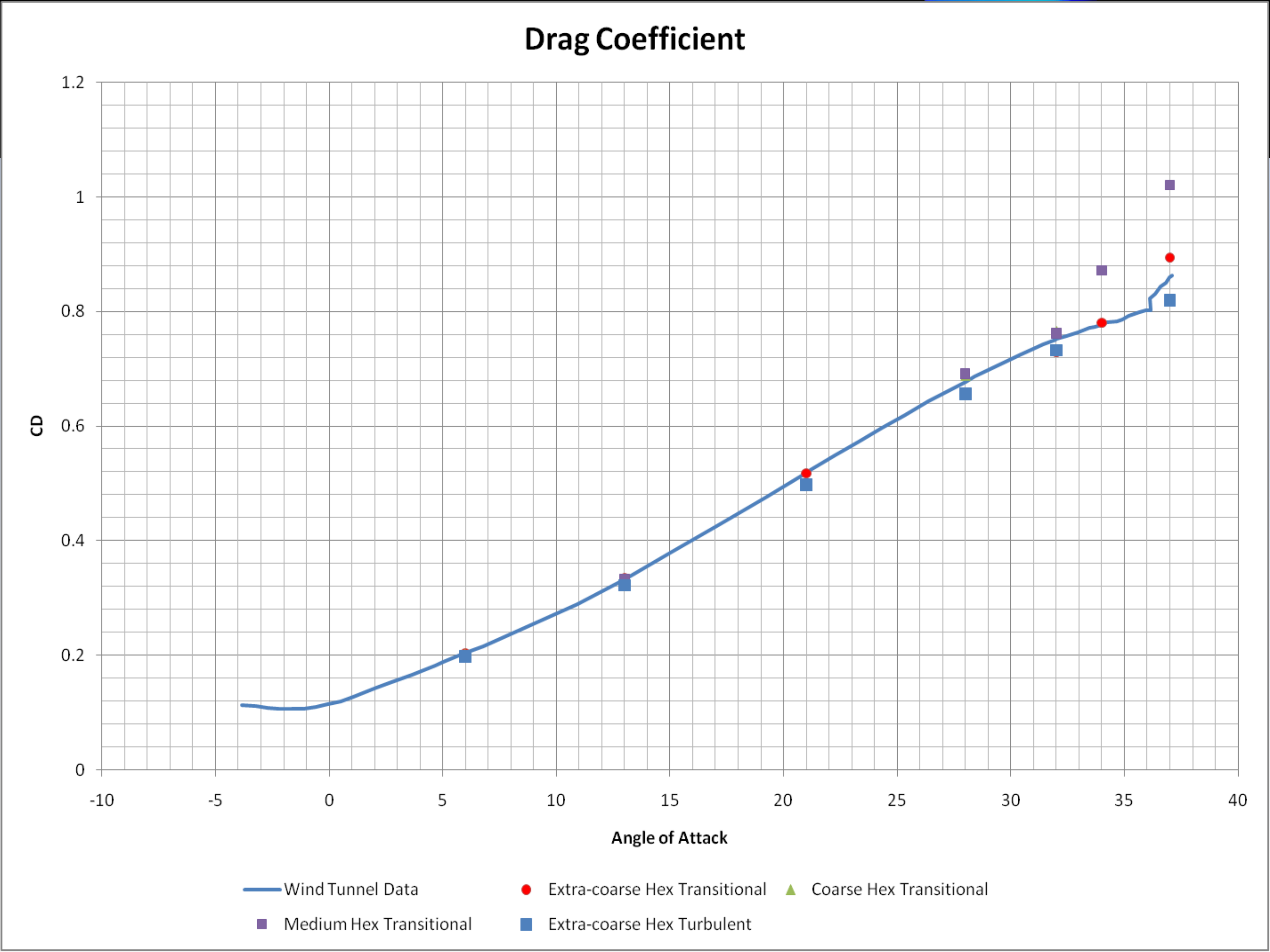
Config 1	6	13	21	28	32	34	37
Extra-coarse	●	●	●	●	●	●	●
Coarse	●	●		●	●		
Medium		●		●	●	●	●
Fine							

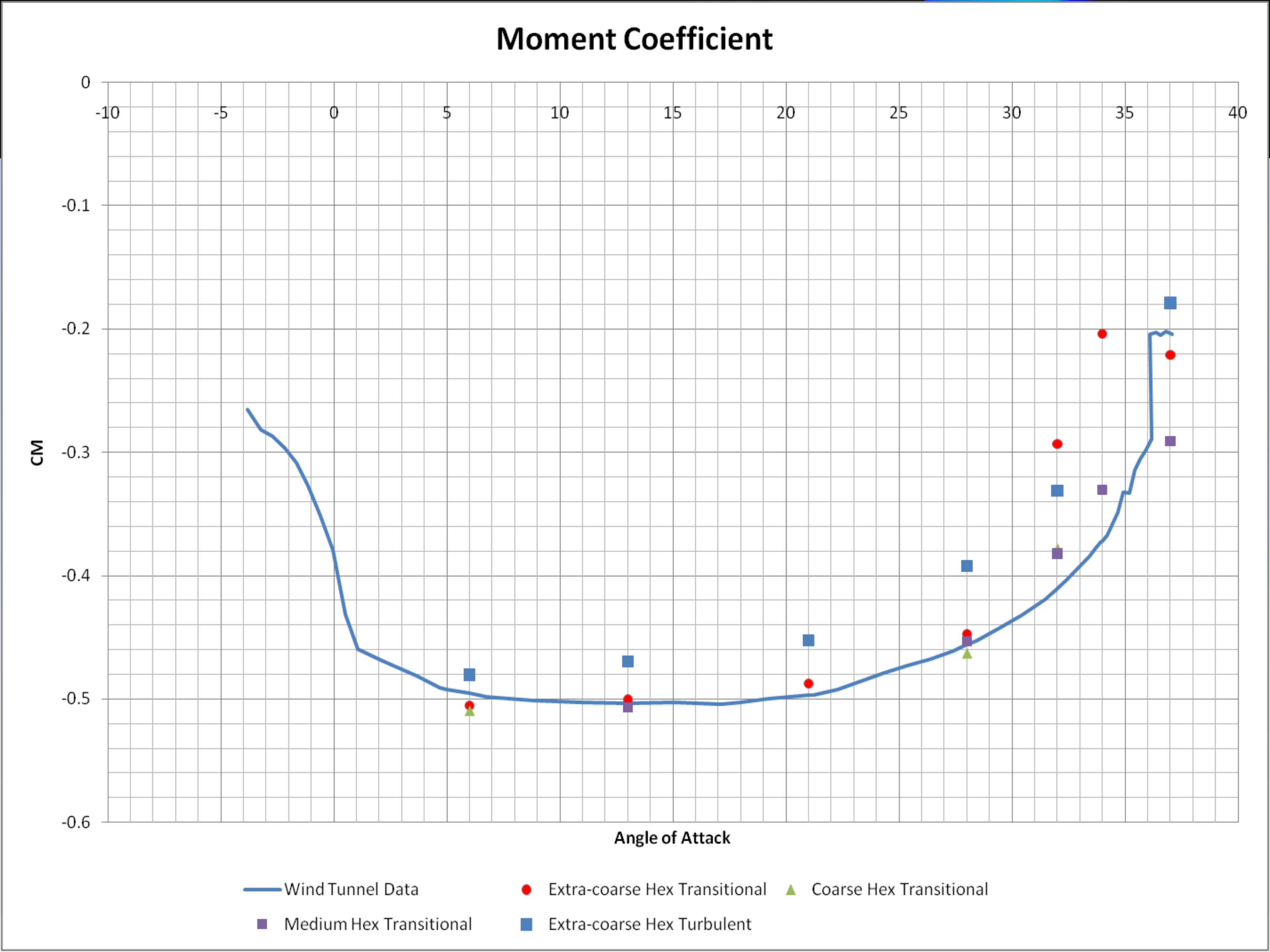
Config 8	6	13	21	28	32	34	37
Medium				●			


Lift Coefficient
3.5
3
2.5
2
1.5
1
0.5
0
-10
-5
0
5
10
15
20
25
30
35
40
Lift Coefficient
Angle of Attack
Wind Tunnel Data
Extra-coarse Hex Transitional
Coarse Hex Transitional
Medium Hex Transitional
Extra-coarse Hex Turbulent

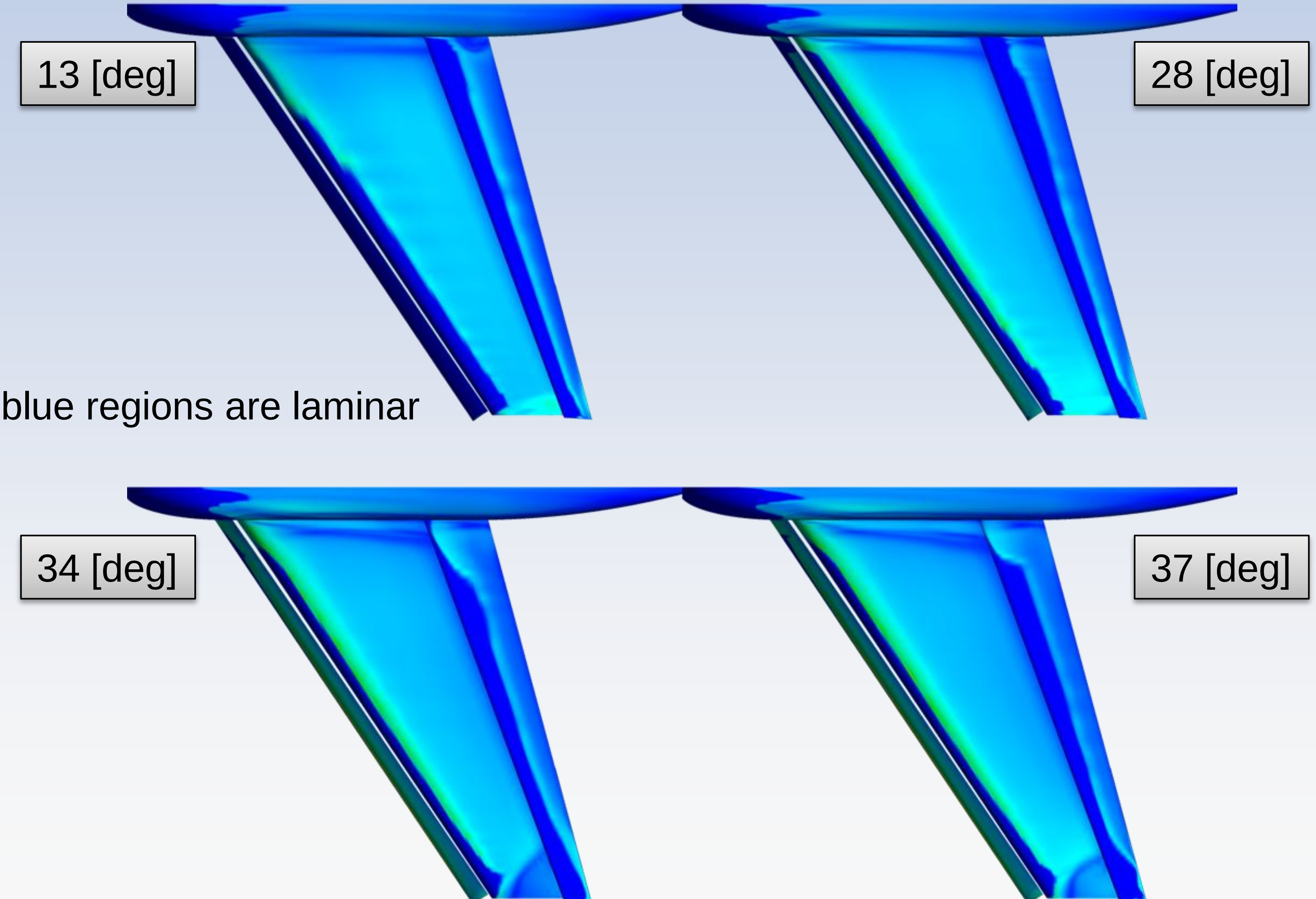


Comparison of CL for Fully Turbulent and Transitional Models
Lift Coefficient
Angle of Attack
3.5
3
2.5
2
1.5
1
0.5
0
-10
-5
0
5
10
15
20
25
30
35
40
Wind Tunnel Data
Extra-coarse Hex Transitional
Extra-coarse Hex Turbulent


Drag Coefficient
CD
1.2
1
0.8
0.6
0.4
0.2
0
-10
-5
0
5
10
15
20
25
30
35
40
Angle of Attack
Wind Tunnel Data
Extra-coarse Hex Transitional
Coarse Hex Transitional
Medium Hex Transitional
Extra-coarse Hex Turbulent

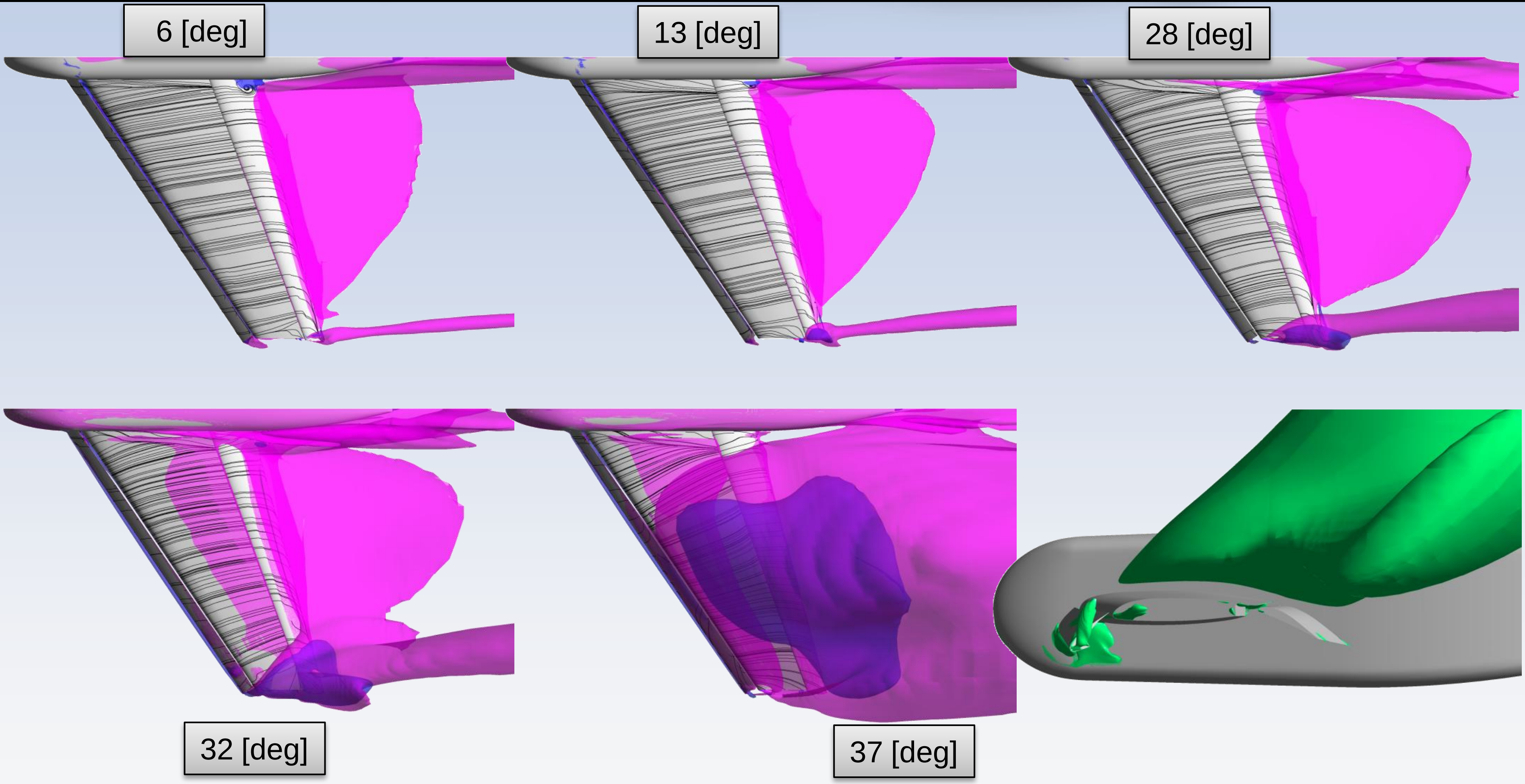

Moment Coefficient
CM
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-10
-5
0
5
10
15
20
25
30
35
40
Angle of Attack
Wind Tunnel Data
Extra-coarse Hex Transitional
Coarse Hex Transitional
Medium Hex Transitional
Extra-coarse Hex Turbulent

Turbulence Intensity near surface (range 0 to 10%) showing transition



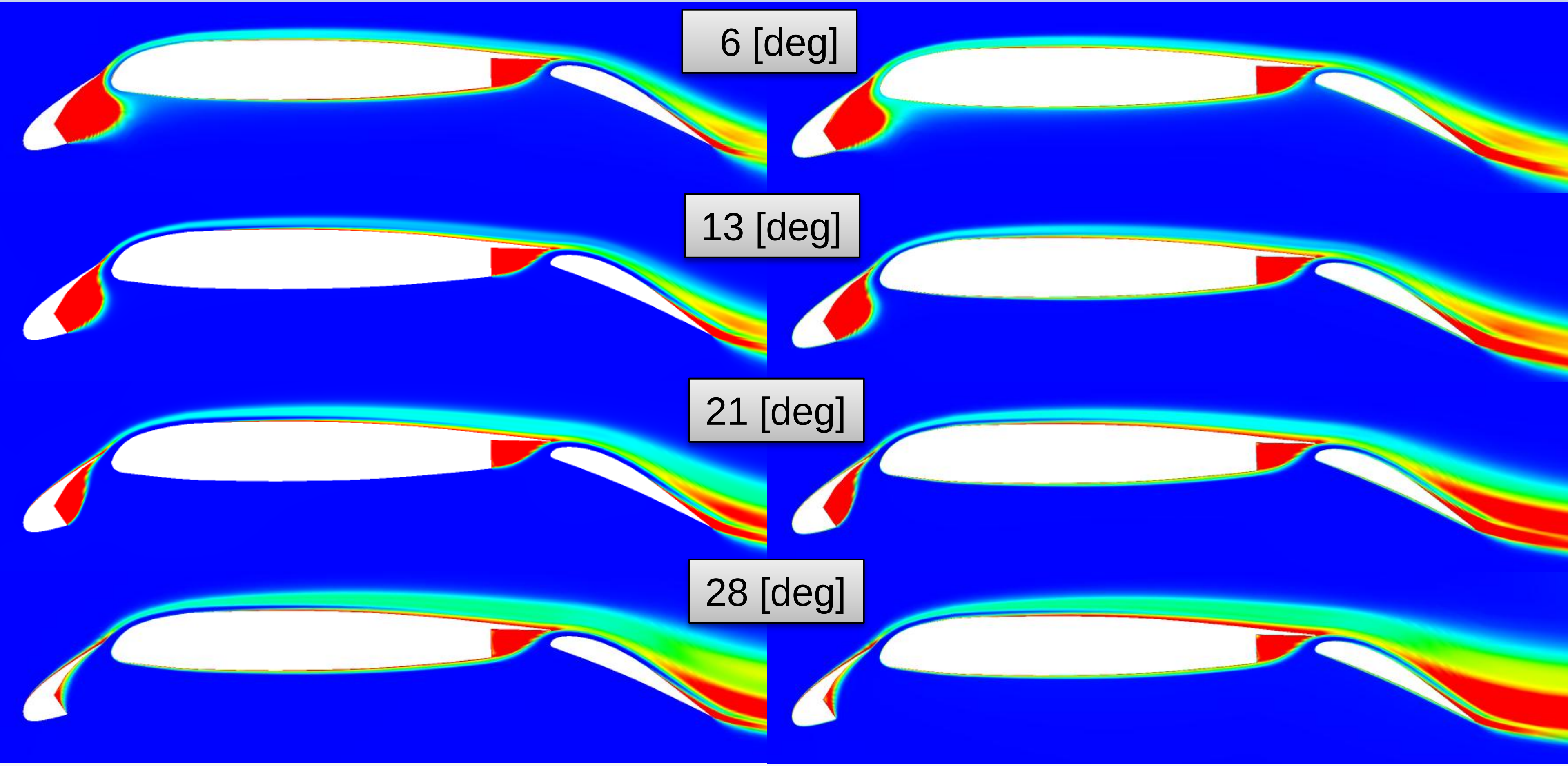
Dark blue regions are laminar

Separation and surface streamlines on coarse grid

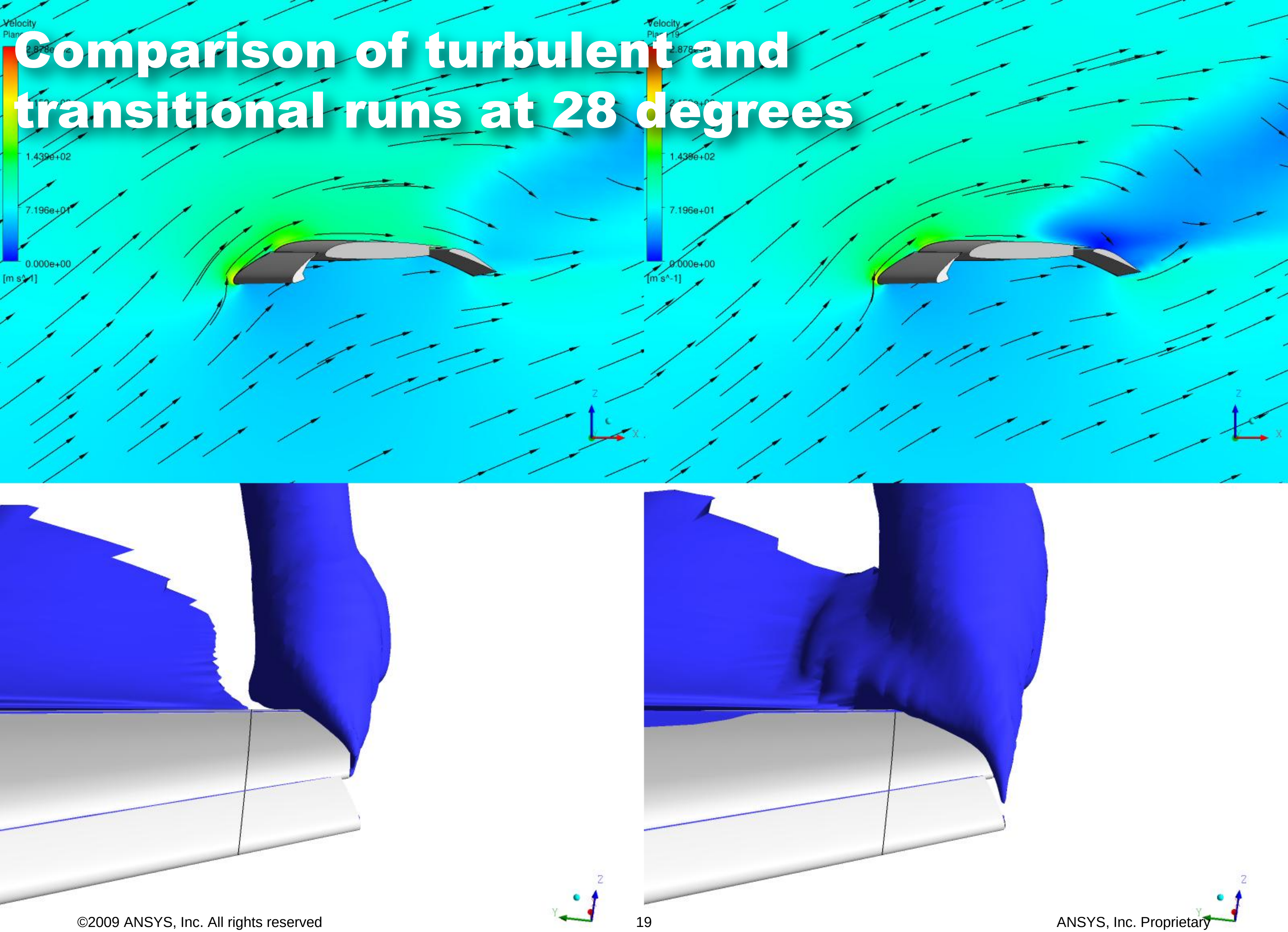


Turbulence Intensity at 65% Span (range 0 to 10%)

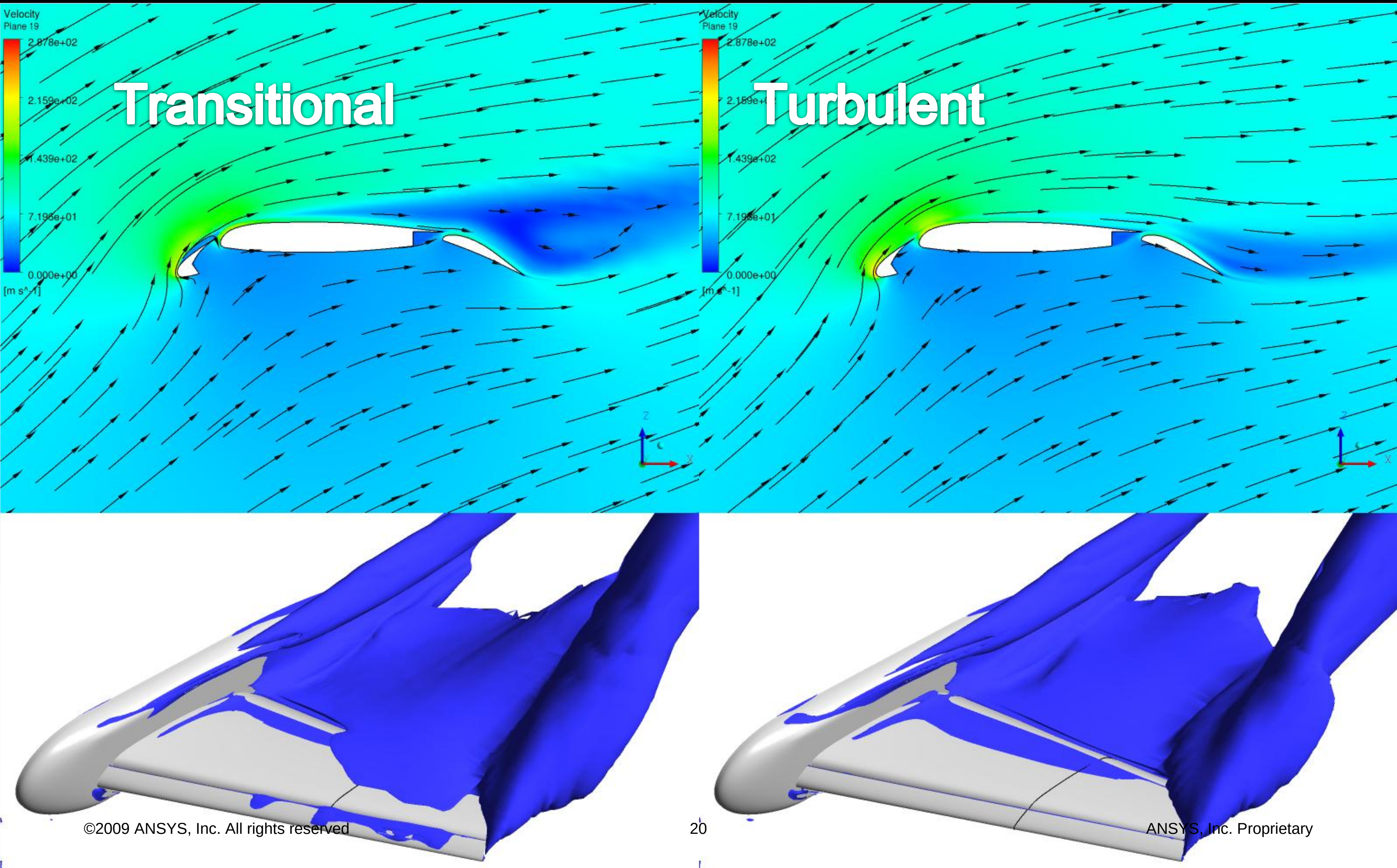
Transitional	Turbulent



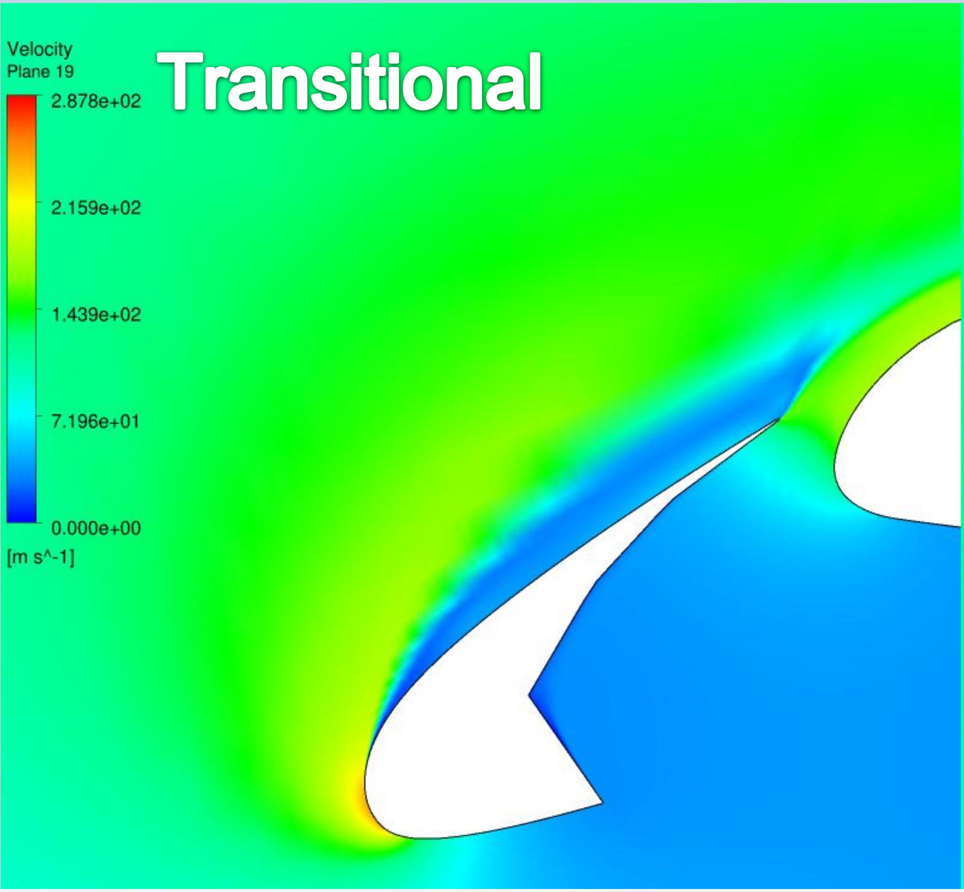
Comparison of turbulent and transitional runs at 28 degrees

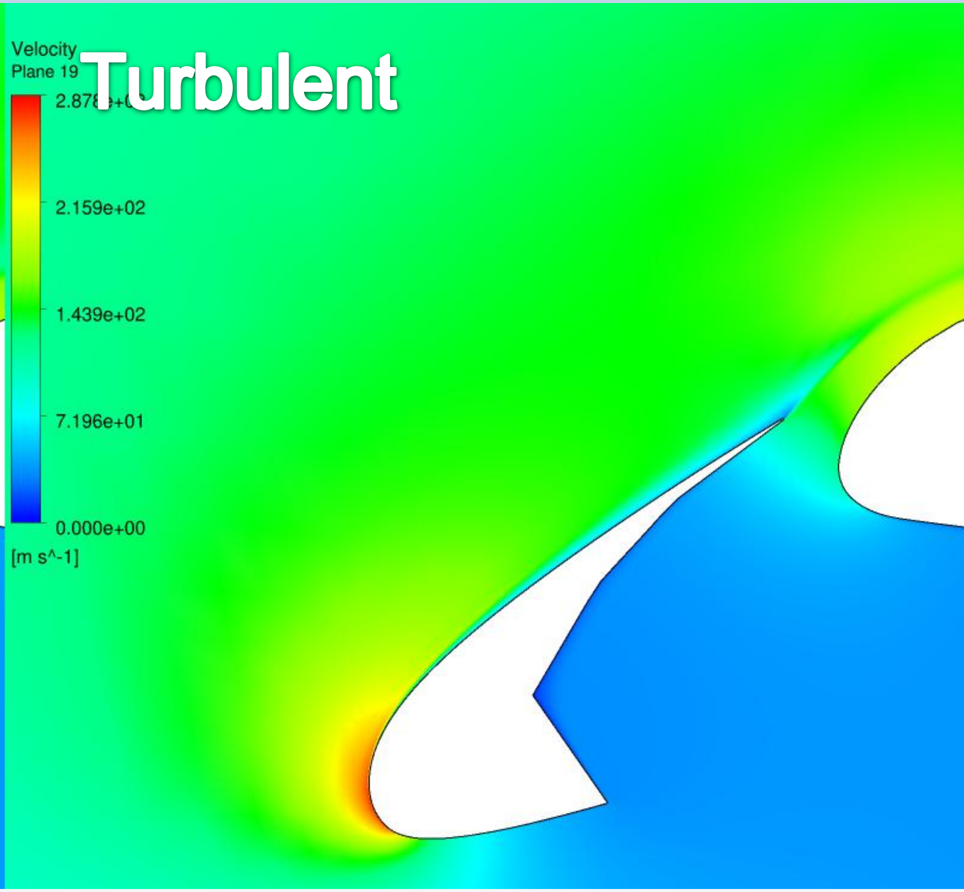


Comparison of turbulent and transitional runs at 32 degrees

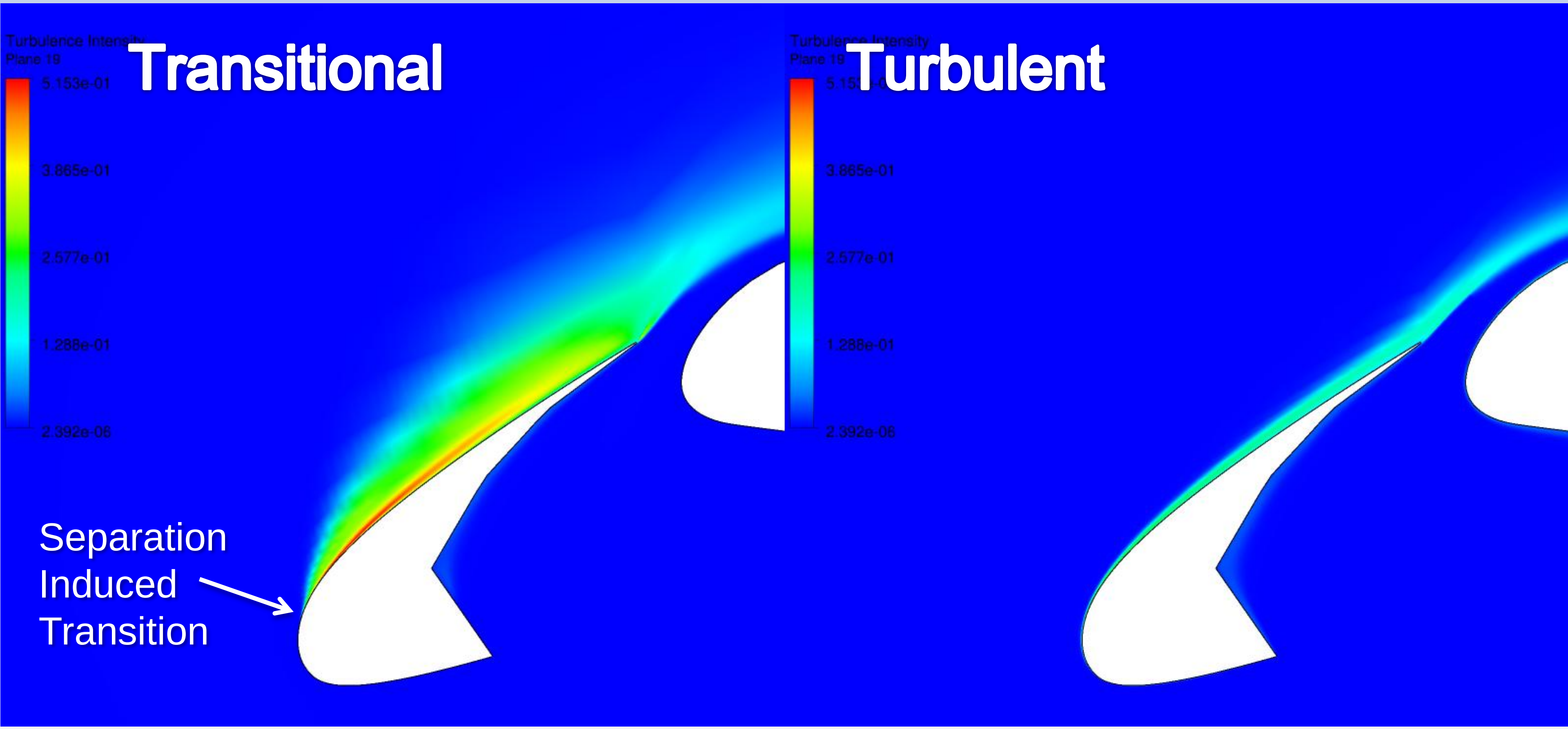


Velocity over slat at 32 degrees



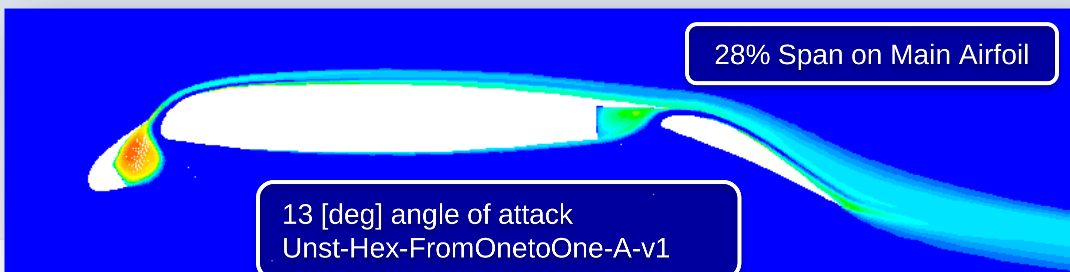


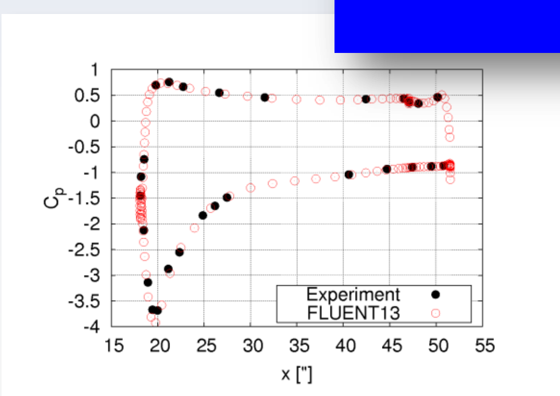
Turbulence Intensity over slat at 37 degrees

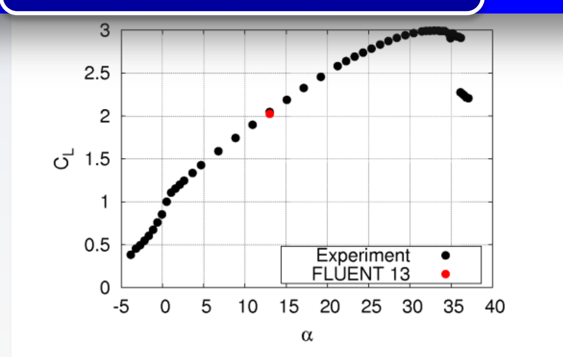


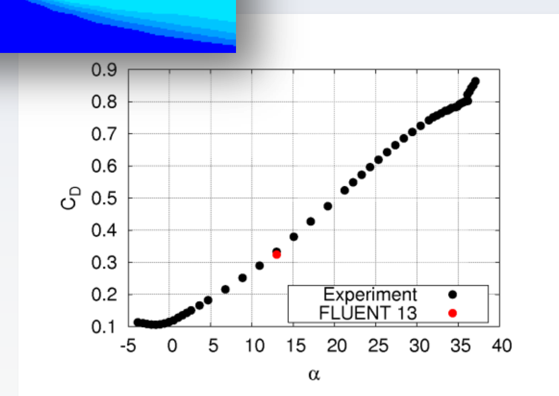
Results from Fluent 13

- **Similar CFD numerics as CFX**
  - Pressure based solver with all-speed mass formulation
  - Rhie-Chow
  - 2nd order numerics
  - Coupled AMG solver
- **Same physical models**
  - SST + Gamma-Theta Transition
  - MAC based timestep to control convergence









Lessons Learned

- **Laminar to turbulent transition causes separation at leading edge of slat**
- **Accurately predicting the transition location is important to**
  - improve prediction of CL, CD and CM
  - capture maximum CL and predict separation
- **Separation location is sensitive to grid**
- **Laminar boundary layer on slat influences secondary flows between slat and main airfoil.**
- **Secondary flows between slat and main airfoil may play an important role in predicting maximum CL**

Next steps?

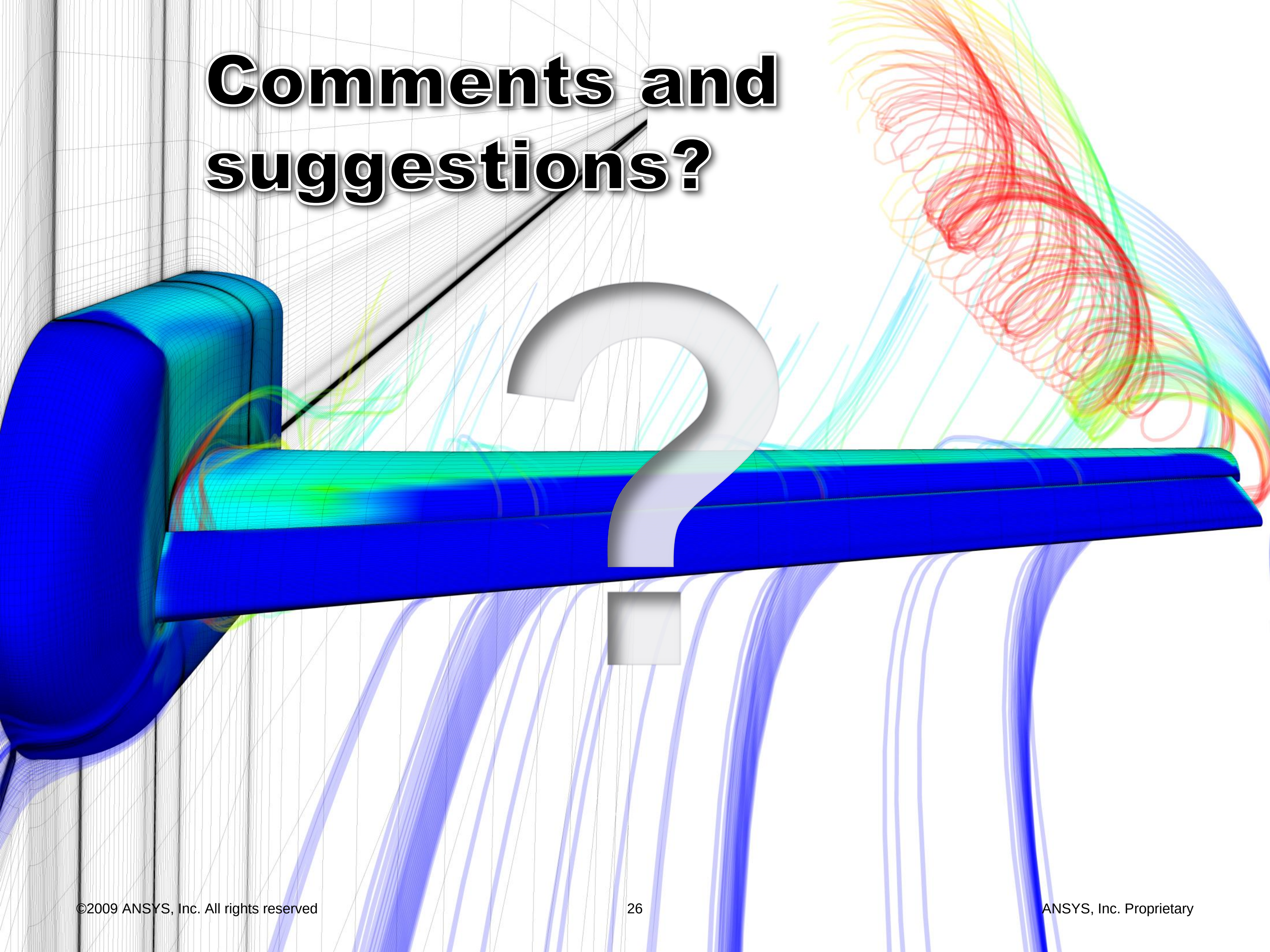
Grid:

- **Improve mesh to improve prediction of transition location**
  – Streamwise refinement in separation region
- **Improve spanwise resolution of secondary flows**

Other

- **Include the effects of structural deformations**

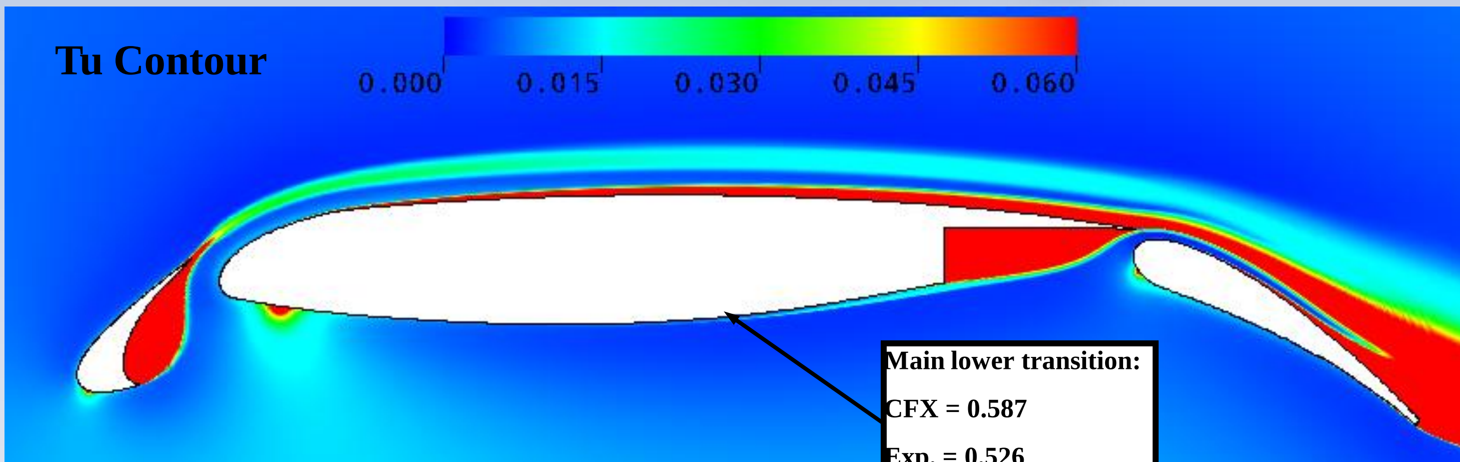
Comments and suggestions?



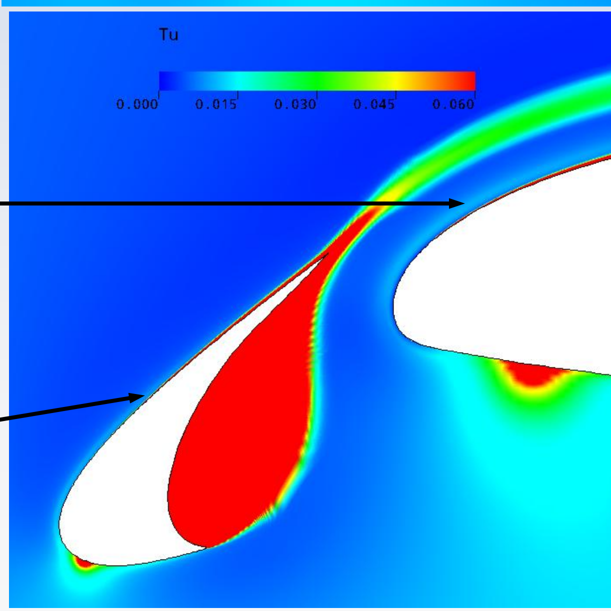
McDonnell Douglas 30P-30N 3-Element Flap

Re = 9 million
Mach = 0.2
C = 0.5588 m
AoA = 8°

Exp. hot film transition location measured as f(x/c)

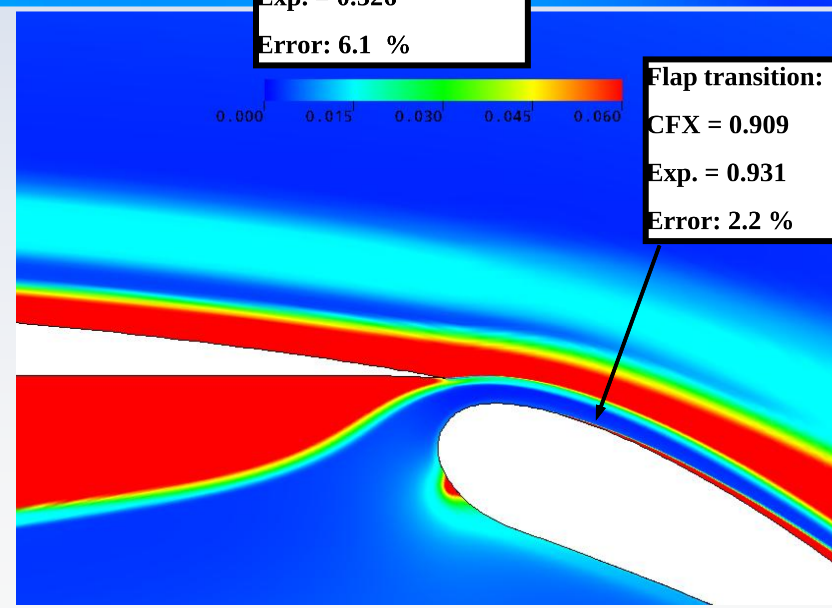


Main lower transition:
CFX = 0.587
Exp. = 0.526
Error: 6.1 %



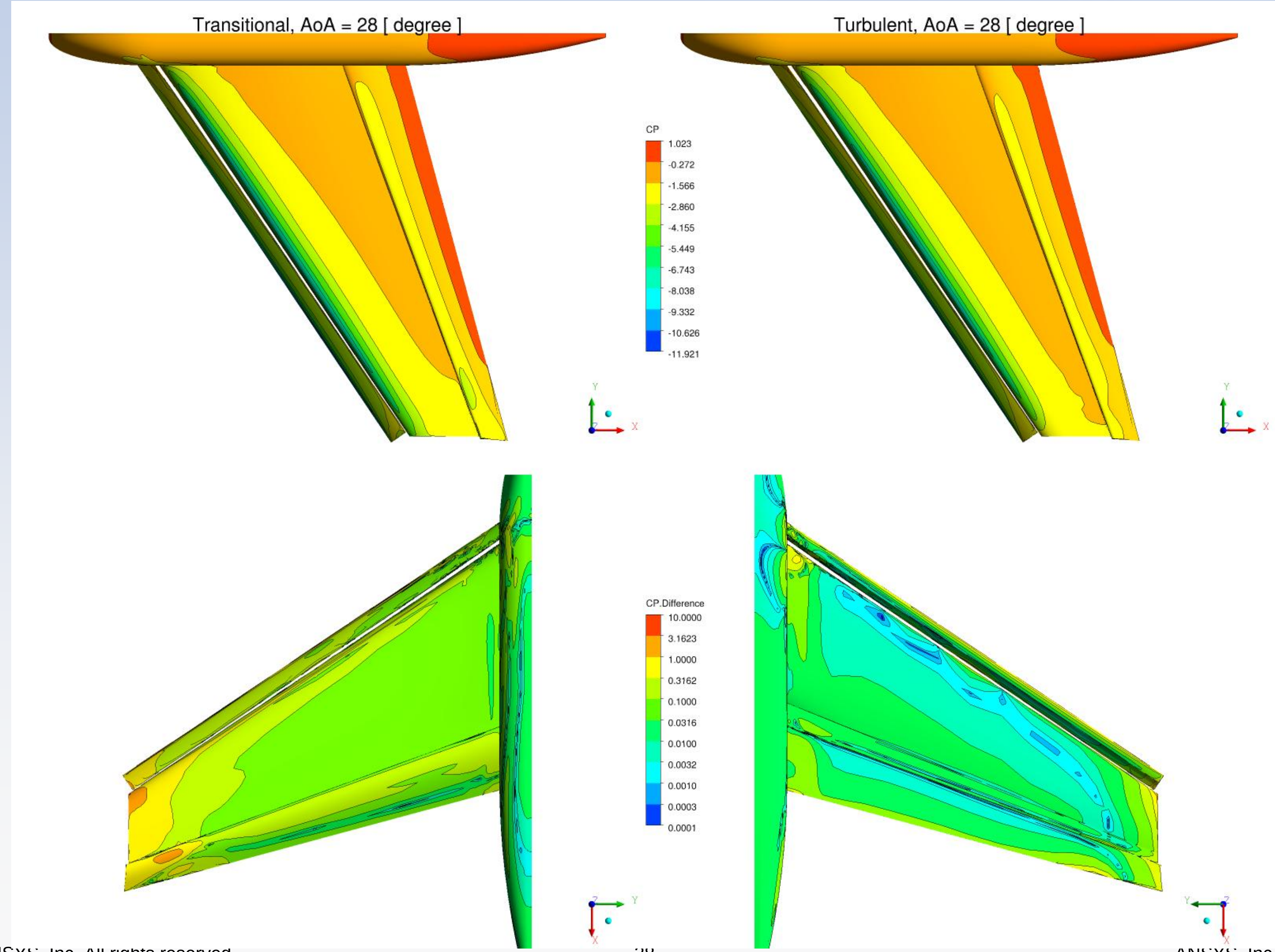
Main upper transition:
CFX = 0.068
Exp. = 0.057
Error: 1.1 %

Slat transition:
CFX = -0.056
Exp.= -0.057
Error: 0.1 %



Flap transition:
CFX = 0.909
Exp. = 0.931
Error: 2.2 %

Compare CP


Transitional, AoA = 28 [degree]
Turbulent, AoA = 28 [degree]
CP
1.023
-0.272
-1.566
-2.860
-4.155
-5.449
-6.743
-8.038
-9.332
-10.626
-11.921
CP.Difference
10.0000
3.1623
1.0000
0.3162
0.1000
0.0316
0.0100
0.0032
0.0010
0.0003
0.0001

Separation and surface streamlines

6 [deg]

13 [deg]

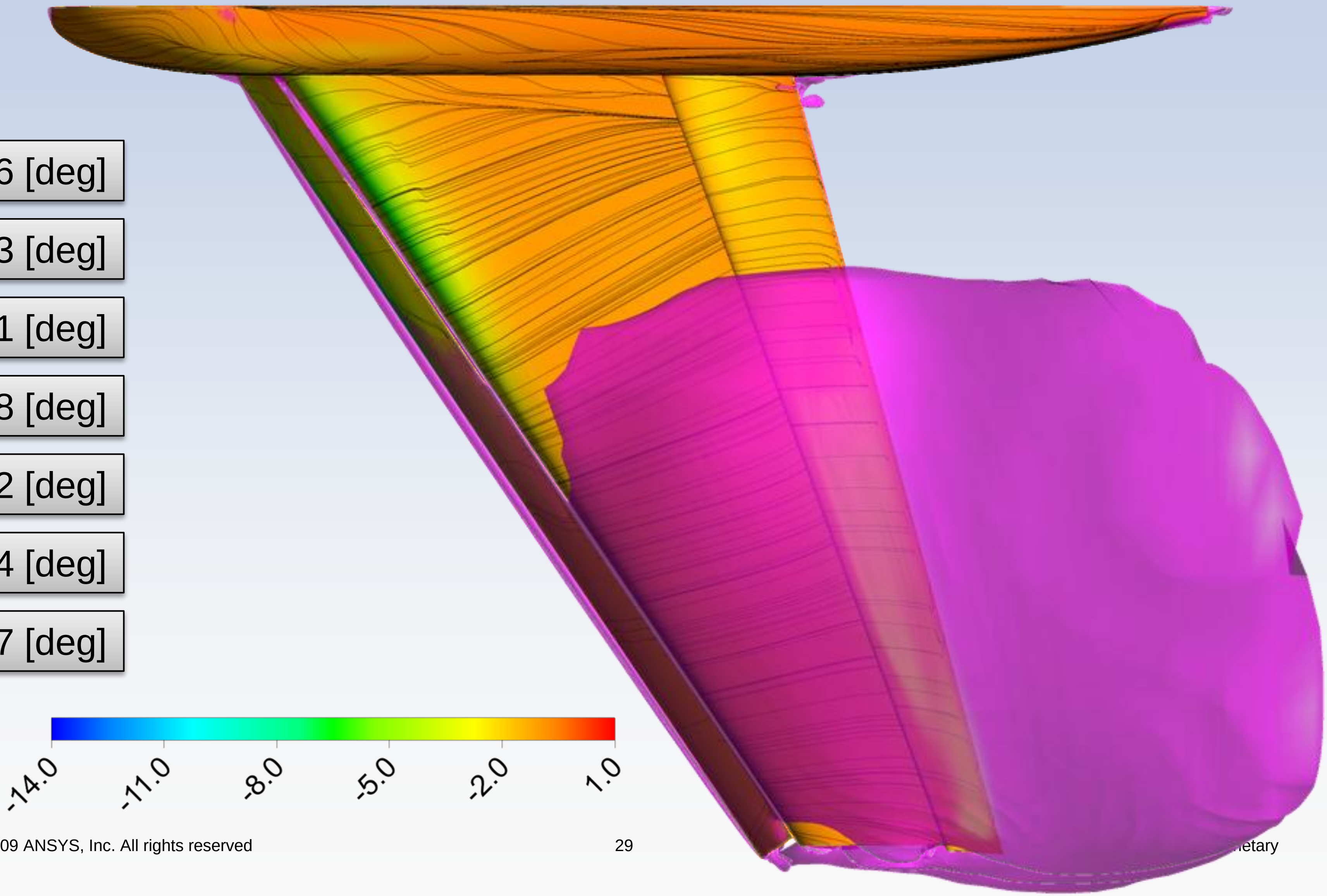
21 [deg]

28 [deg]

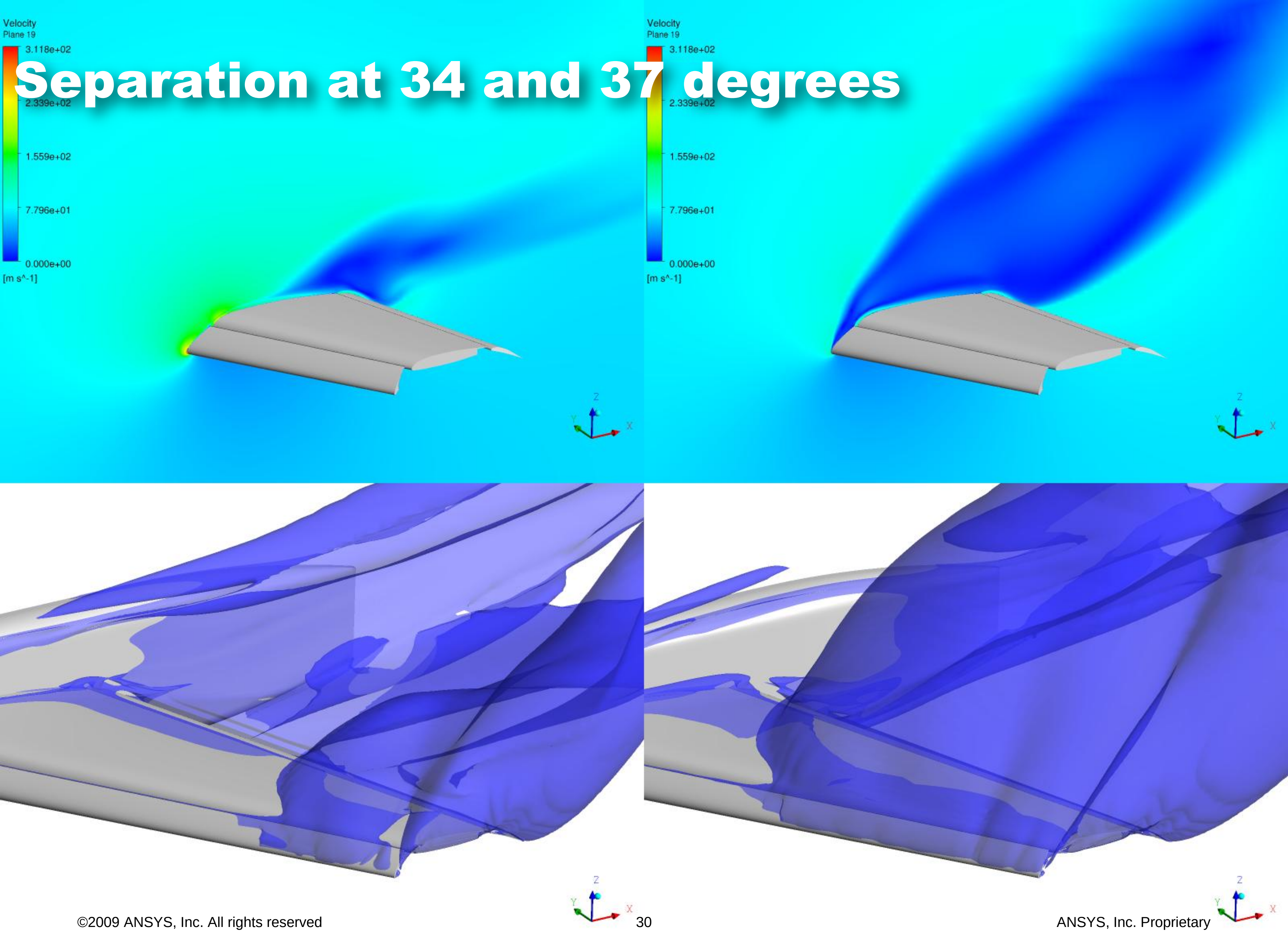
32 [deg]

34 [deg]

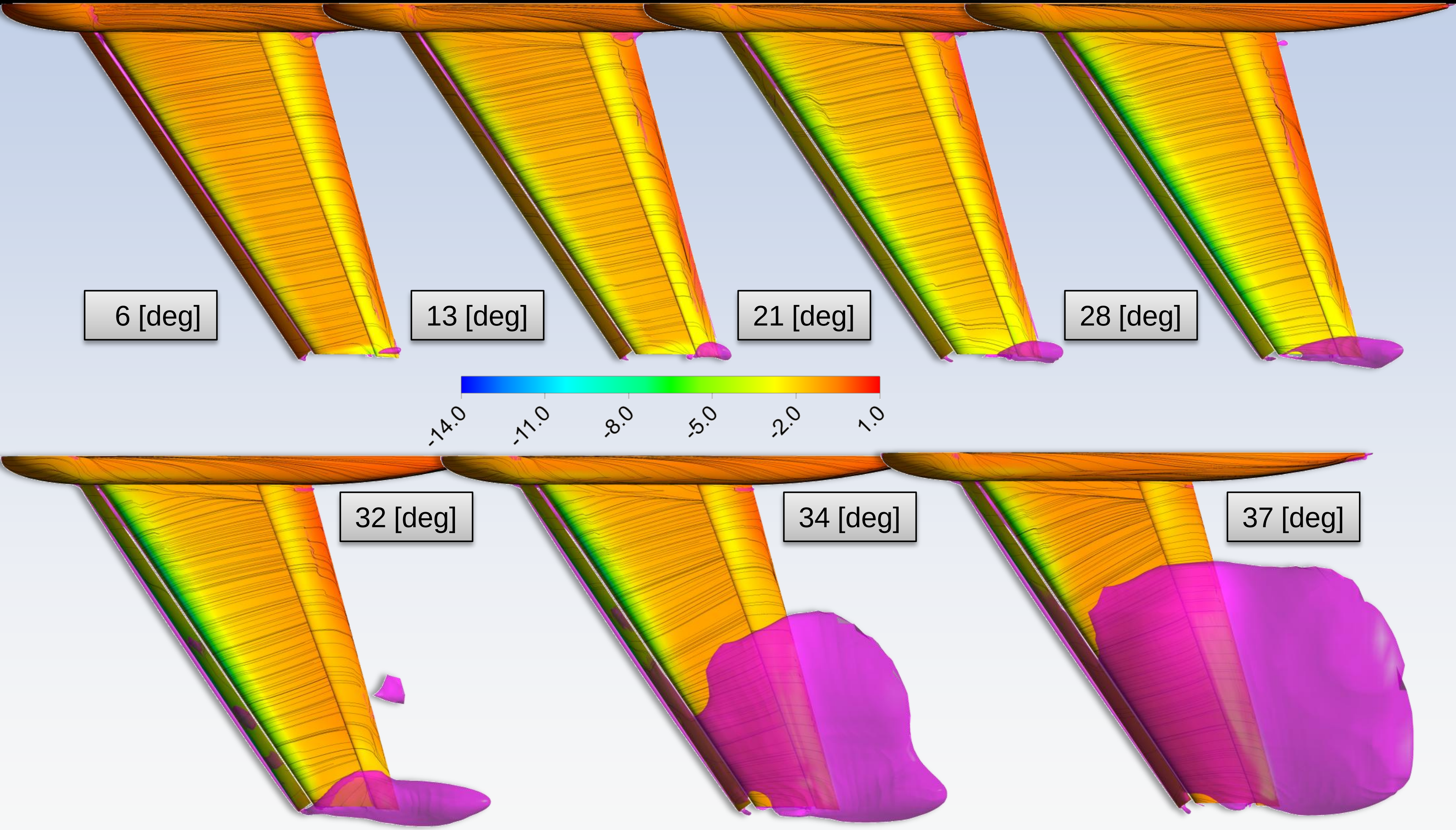
37 [deg]



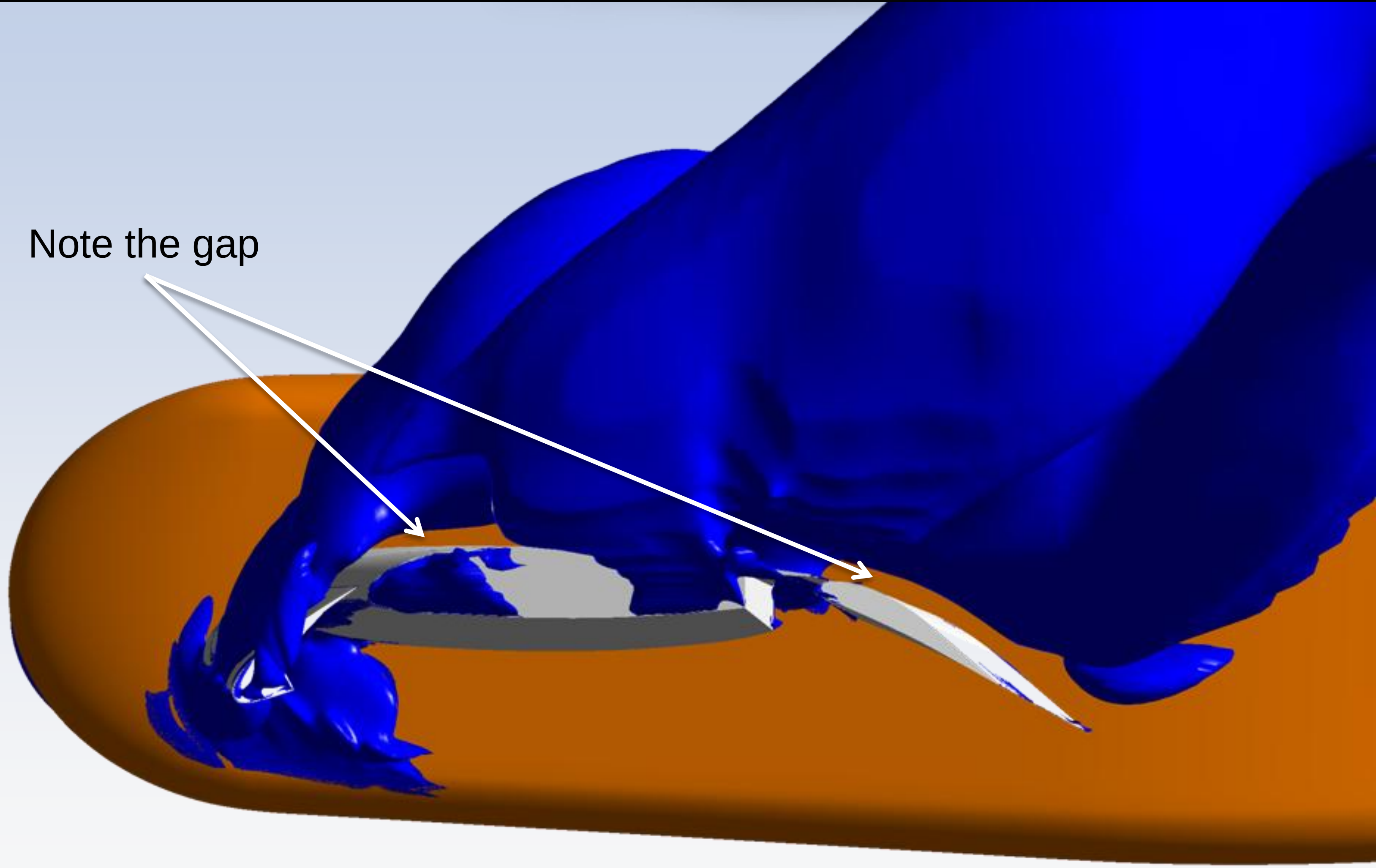
Separation at 34 and 37 degrees



Separation and surface streamlines on extra-coarse grid



Location of recirculation



Miscellaneous

- **Useful additional variables**

  Turbulence Intensity = sqrt(2/3*Turbulence Kinetic Energy)/<airspeed | Velocity>

- **Visualizing separation**
  - Create isosurface = 0.9*airspeed
  - Clip isosurface to
    - Less than Inlet total pressure (eliminates regions below airfoil) and greater than .25 [cm] wall distance